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(54) Method and apparatus for therapeutic electromagnetic treatment

(57) A therapeutic treatment device for treating a treatment region comprising an incoherent, pulsed, light source operable to provide a light output for treatment, a power supply connected to the light source, a housing including a reflector and having an opening, wherein the light source is disposed within the housing and the reflector reflects light from the light source to the opening. A flexible light guide is disposed between the opening and the treatment region, wherein the light guide receives the incoherent light from the light source and transmits the light to the treatment region and the light source, reflector and light guide cooperate to provide *between* 6 and 100 *J/cm*^{2} *to the* skin.

The light guide transmits light having a predetermined angular divergence, wherein the divergence is selected in response to a desired treatment depth.

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Description

The present invention relates generally to the art of therapeutic electromagnetic treatment and more specifically to a method and apparatus for utilizing a spatially extended pulsed light source such as a flashlamp (flash tube) for such treatment or efficiently focusing light from the flashlamp into optical fibers for therapeutic treatment or other applications.

This application is a continuation-in-part of prior co-pending United States application Serial No. 07/964,210, filed October 20, 1992, entitled "Method And Apparatus For Therapeutic Electromagnetic Treatment."

It is known in the prior art to use electromagnetic radiation in medical application for therapeutic uses such as treatment of shin disorders. For example, U.S. Patent No. 4,298,005 to Mutzhas describes a continuous ultraviolet lamp with cosmetic, photobiological, and photochemical applications. A treatment based on using the UV portion of the spectrum and its photochemical interaction with the skin is described. The power delivered to the skin using Mutzhas' lamp is described as 150Whm^2, which does not have a significant effect on skin temperature.

In addtion to prior art treatment involving UV light, lasers have been used for dermatological procedures, including Argon lasers, CO_2 lasers, Nd(Yag) lasers, Copper vapor lasers, ruby lasers and dye lasers. For example, U.S. Patent No. 4,829,262 to Furumoto, describes a method of constructing a dye laser used in dermatology applications. Two skin conditions which may be treated by laser radiation are external skin Irregularities such as local differences in the pigmentation or structure of the skin, and vascular disorders lying deeper under the skin which cause a variety of skin abnormalities including port wine stains, telangiectasias, leg veins and cherry and spider angiomas. Laser treatment of these skin disorders generally includes localized heating of the treatment area by absorption of laser radiation. Heating the shin changes or corrects the skin disorder and causes the full or partial disappearance of the skin abnormality.

Certain external disorders such as pigmented lesions can also be treated by heating the skin very fast to a high enough temperature to evaporate parts of the skin. Deeper-lying vascular disorders are more typically treated by heating the blood to a high enough temperature to cause it to coagulate. The disorder will then eventually disappear. To control the treatment depth a pulsed radiation source is often used. The depth the heat penetrates in the blood vessel is controlled by controlling the pulse width of the radiation source. The absorption and scattering coefficients of the skin also affect the heat penetration. These coefficients area function of the constituents of skin and the wavelength of the radiation. Specifically, the absorption coefficient of light in the epidermis and dermis tends to be a slowly varying, Monotonically decreasing function of wavelength. Thus, the wavelength of the light should be chosen so that the absorption coefficient is optimized for the particular skin condition and vessel size being treated.

The effectiveness of lasers for applications such as tattoo removal and removal of birth and age marls is diminished because lasers are monochromatic. A laser of a given wavelength may be effectively used to treat a first type of skin pigmentation disorder, but, if the specific wavelength of the laser is not absorbed efficiently by skin having a second type of disorder, it will be ineffective for the second type of skin disorder. Also, lasers are usually complicated, expensive to manufacture, large for the amount of power delivered, unreliable and difficult to maintain.

The wavelength of the light also affects vascular disorder treatment because blood content in the vicinity of the vascular disorders varies, and blood content affects the absorption coefficient of the treatment area. Oxyhemogiobin is the main chromophore which controls the optical properties of blood and has strong absorption bands in the visible region. More particularly, the strongest absorption peak of oxyhemoglobin occurs at 418nm and has a band-width of 60nm. Two additional absorption peals with lower absorption coefficients occur at 542 and 577nm. The total band-width of these two peals is on the order of 100nm. Additionally, light in the wavelength range of 500 to 600nm is desirable for the treatment of blood vessel disorders of the skin since it is absorbed by the blood and penetrates through the skin. Longer wavelengths up to 1000nm are also effective since they can penetrate deeper into the skin, heat the surrounding tissue and, if the pulse-width is long enough, contribute to heating the blood vessel by thermal conductivity. Also, longer wavelengths are effective for treatment of larger diameter vessels because the lower absorption coefficient is compensated for by the longer path of light in the vessel.

Accordingly, a wide band electromagnetic radiation source that covers the near UV and the visible portion of the spectrum would be desirable for treatment of external skin and vascular disorders. The overall range of wavelengths of the light source should be sufficient to optimize treatment for any of a number of applications. Such a therapeutic electromagnetic radiation device should also be capable of providing an optimal wavelength range within the overall range for the specific disorder being treated. The intensity of the light should be sufficient to cause the required thermal effect by raising the temperature of the treatment area to the regtired temperature. Also, the pulse-width should be variable over a wide enough range so as to achieve the optimal penetration depth for each application. Therefore, it Is desirable to provide a light source having a wide range of wavelengths, which can be selected according to the required skin treatment, with a controlled pulse-width and a high enough energy density for application to the affected area.

Pulsed non-laser type light sources such as linear flashlamps provide these benefits. The intensity of the emitted light can be made high enough to achieve the required thermal effects. The pulse-width can be varied over a wide range so that control of thermal depth penetration can be accomplished. The typical spectrum covers the visble and ultraviolet range and the optical bands most effective for specific applications can be selected, or enhanced using fluorescent

materials. Moreover, non-laser type light sources such as flashlamps are much simpler and easier to manufacture than lasers, are significantly less expensive for the same output power and have the potential of being more efficient and more reliable. They have a wide spectral range that can be optimized for a variety of specific skin treatment applications. These sources also have a pulse length that can be varied over a wide range which is critical for the different types of skin treatments.

In addition to being used for treating skin disorders, lasers have been used for invasive medical procedures such as lithotripsy and removal of blood vessel blockage. In such invasive procedures laser light is coupled to optical fibers and delivered through the Mar to the treatment area. In lithotripsy the fiber delivers light from a pulsed laser to a kidney or gallstone and the light interaction with the stone creates a shock wave which pulverizes the stone. To remove blood vessel blockage the light is coupled to the blockage by the fber and disintegrates the blockage. In either case the shortcomings of lasers discussed above with respect to laser skin treatment are present Accordingly, a treatment device for lithotripsy and blockage removal utilizing a flashlamp would be desirable.

To effectively treat an area the light from the source must be focussed on the treatment area. Coupling pulsed laser light into optical fbers in medicine is quite common. The prior art describes coupling isotropic incoherent point sources such as CW lamps into small optical fibers. For example, U.S. Patent No. 4,757,431, issued July 12, 1988, to Cross, at al. discloses a method for focusing incoherent point sources with small filaments or an arc lamp with an electrode separation of 2mm into a small area. Point (or small) sources are relatively easy to focus without large losses In energy because of the small size of the source. Also, U. S. Patent No. 4,022,534. Issued May 10, 1977, to Kshner discloses light produced by a flash tube and the collection of only a small portion of the light emitted by the tube into an optical fiber.

However, the large dimension of an extended source such as a flashlamp makes it difficult to focus large fractions of its energy into small areas. Coupling into optical fibers is even more difficult since not only must a high energy density be achieved, but the angular distribution of the light has to be such that trapping In the optical fiber can be accomplished. Thus, it is desirable to have a system for coupling the output of a high intensity, extended, pulsed light source into an optical flier.

According to a first embodiment of the invention a therapeutic treatment device comprises a housing and an incoherent light source, suitably a flashlamp, operable to provide a pulsed light output for treatment, disposed in the housing. The housing has an opening and is suitable for being disposed adjacent a skin treatment area. A reflector is mounted within the housing proximate the light source, and at least one optical fitter is mounted proximate the opening in the housing. An Iris Is mounted coextensively with the opening. Power to the lamp is provided by a variable pulse width pulse forming circuit. Thus, the treatment device provides controlled density, filtered, pulsed fight output through an opening in the housing to a skin area for treatment

According to a second embodiment of the invention a method of treatment with light energy comprises the steps of providing a high power, pulsed light output from a non-laser, incoherent light source and directing the pulsed light output to a treatment area. The pulse width of the light output is controlled and focussed so that the power density of the light is controlled. Also, the light is filtered to control the spectrum of the light

According to a third embodiment of the invention a coupler comprises an incoherent light source such as a toroidal flashlamp. A reflector is disposed around the incoherent fight source and at least one optical fiber or light guide. The fiber has an end disposed within the reflector. This end collects the light from the circular lamp. In a similar coupling configuration fbers may be provided, along with a linear to circular flier transfer unit disposed to receive light from the light source and provide light to the optical fibers. The reflector has an elliptical cross-section in a plane parallel to the axis of the linear flash tube, and the linear flash tube is located at one focus of the ellipse while the linear to circular transfer unit is located at the other focus of the ellipse.

For a better understanding of the invention, reference is made to the accompanying drawings. In which like numerals designate corresponding elements or sections throughout, and in which:

Figure 1 is a cross-sectional view of an incoherent, pulsed light source skin treatment device;
Figure 2 is a side view of the light source of Figure 1;
Figure 3 is a schematic diagram of a pulse forming network with a variable pulse width for use with the skin treatment device of Figures 1 and 2;
Figure 4 is a cross-sectional view of a coupler for coupling light from a toroidal flash tube into an optical fiber with a conical edge;
Figure 5 is a side view of a toroidal flash tube;
Figure 6 is a top view of a toroidal flash tube;
Figure 7 shows the geometry for coupling into a cortical section;
Figure 8 is a cross-sectional view of a coupler for coupling light from a toroidal flash tube into an optical fiber with a flat edge;
Figure 9 is a front sectional view of a coupler for coupling light from a linear flash tube into a circular fiber bundle;
Figure 10 is a side sectional view of the coupler of Figure 9;

Figure 11 is a front view of a coupler for coupling light from a linear flash tube into an optical fiber bar;

Figure 12 is a front view of a coupler for coupling light from a linear flash tube into a doped optical fiber;

Figure 13 is a schematic configuration of a gel skin Interface with a transparent plate;

Figure 14 shows an angular distribution of photons penetrating without using a gel;

Figure 15 shows a light guide providing a large angular divergence;

Figure 16 shows a light guide providing a narrow angular divergence;

Figure 17 shows a spectra produced with a flashlamp current of 200 amps;

Figure 18 shows a spectra produced with a flashlamp current of 200 amps; and

Figure 19 shows a GTO driver circuit for a flashlamp.

In the various figures, like reference numerals are used to describe like components.

Before explaining at least one embociment of the Invention in detail it is to be understood that the invention Is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Referring now to Figures 1 and 2, cross-sectional and side viers of an incoherent, pulsed light source skin treatment device 10 constructed and operated in accordance with the principles of the present invention are shown. The device 10 may be seen to include a housing 12, having an opening therein, a handle 13 (Figure 2 only), a light source 14 having an outer glass tube 15, an elliptical reflector 16, a set of optical lifters 18, an iris 20 and a detector 22 (Figure 1 only).

Light source 14, which is mounted in housing 12, may be a typical incoherent light source such as a gas filled linear flashlamp Model No. 15568 available from ILC. The spectrum of light emitted by gas filled linear flashlamp 14 depends on current density, type of glass envelope material and gas mixture used in the tube. For large current densities (e.g., 3000 NCm^2 or more) the spectrum is similar to a black body radiation spectrum. Typically, most of the energy is emitted in the 300 to 1000 nm wavelength range.

To treat a skin (or visible) disorder a required light density on the skin must be delivered. This light density can be achieved with the focusing arrangement shown In Figures 1 and 2. Figure 1 shows a cross-section view of reflector 16, also mounted in housing 12. As shown In Figure 1, the cross-section of reflector 16 In a plane is perpendicular to the axis of flashlamp 14 is an ellipse. Linear flashlamp 14 Is located at one focus of the ellipse and reflector 16 is positioned in such a way that the treatment area of skin 21 is located at the other focus. The arrangement shown Is similar to focusing arrangements used with Lasers and efficiently couples right from flashlamp 14 to the skin. This arrangement should not, however, be considered limiting. Elliptical reflector 16 may be a metallic reflector, typically polished aluminum which is an easily machinable reflector and has a very high reflectivity in the visible, and the UV range of the spectrum can be used. Other bare or coated metals can also be used for this purpose.

Optical and neutral density filers 18 are mounted in housing 12 near the treatment area and may be moved into the beam or out of the beam to control the spectrum and intensity of the light Typically, 50 to 100nm bandwidth filters, as well as low cutoff filers in the visible and ultraviolet portions of the spectrum, are used. In some procedures it is desirable to use most of the spectrum, with only the UV portion being cut off. In other applications, mainly for deeper penetration, it is preferable to use narrower bandwidths. The bandwidth filters and the cutoff filters are readily available commercially.

Glass tube 15 is located coaxially with flashlamp 14 and has fluorescent material deposited on it. Glass tube 15 will typically be used for treatment of coagulation of blood vessels to optimize the energy efficiency of device 10. The fluorescent material can be chosen to absorb the IN portion of the spectrum of flashlamp 14 and generate light in the 500 to 650nm range that is optimized for absorption in the blood. Similar materials are coated on the inner walls of commercial fluorescent lamps. A typical material used to generate 'warm' white light in fluorescent lamps has a conversion efficiency of 80%, has a peak emission wavelength of 570nm and has a bandwidth of 70nm and is useful for absorption in blood. The few millisecond decay time of these phosphors is consistent with long pulses that are required for the treatment of blood vessels.

Other shapes or configurations of flashlamp 14 such as circular, helical, short arc and multiple linear flashlamps may be used. Reflector 16 may have other designs such as parabolic or circular reflectors. The light source can also be used without a reflector and the required energy and power density may be achieved by locating light source 14 in close proximity to the treatment area.

Iris 20 is mounted in housing 12 between optical filters 18 and the treatment area and controls the length and the width of the exposed area, i.e. by collimating the output of flashlamp 14. The length of flashlamp 14 controls the maximum length that can be exposed. Typically an 8cm long (arc length) tube will be used and only the central 5cm of the tube is exposed. Using the central 5cm assures a high degree of uniformity of energy density in the exposed skin area. Thus, In this embodiment the iris 20 (also called a collimator) will enable exposure of skin areas of a maximum length of 5cm. The iris 20 may be closed to provide a minimum exposure length of one millimeter. Similarly, the width of the

exposed skin area can be controlled in the range of 1 to 5 mm for a 5 mm wide flashlamp. Larger exposed areas can be easily achieved by using longer flash tubes or multiple tubes, and smaller exposure areas are obtainable with an iris that more completely collimates the beam. The present invention provides a larger exposure area compared to prior art lasers or point sources and is very effective in the coagulation of blood vessels since blood flow interruption over a longer section of the vessel is more effective in coagulating it. The larger area exposed simultaneously also reduces the required procedure time.

Detector 22 (Figure 1) is mounted outside housing 12 and monitors the light reflected from the skin. Detector 22 combined with optical fiters 18 and neutral density fifters can be used to achieve a quick estimate of the spectral reflection and absorption coefficients of the skin. This may be carried out at a low energy density level prior to the application of the main treatment pulse. Measurement of the optical properties of the skin prior to the application of the main pulse is useful to determine optimal treatment conditions. As stated above, the wide spectrum of the light emitted from the non-laser type source enables investigation of the skin over a wide spectral range and choice of optimal treatment wavelengths.

In an alternative embodiment, detector 22 or a second detector system may be used for real-time temperature measurement of the skin during its exposure to the pulsed light source. This is useful for skin thermolysis applications with long pulses. In which light is absorbed In the epidermis and dermis. When the external portion of the epidermis reaches too high a temperature, permanent scarring of the skin may result. Thus, the temperature of the skin should be measured. This can be realized using infra-red emission of the heated skin, to prevent over-exposure.

A typical real-time detector system would measure the infra-red emission of the skin at two specific wavelengths by using two detectors and filters. The ratio between the signals of the two detectors can be used to estimate the instantaneous skin temperature. The operation of the pulsed fight source can be stopped if a preselected skin temperature is reached. This measurement is relatively easy since the temperature threshold for pulsed heating that may cause skin scarring Is on the order of 50°C or more, which Is easily measurable using infra-red emission.

The depth of heat penetration depends on the fight absorption and scattering in the different layers of the skin and the thermal properties of the skin. Mother Important parameter is pulse-width. For a pulsed fight source, the energy of which is absorbed in an infinitesimally thin layer, the depth of heat penetration (d) by thermal conductivity during the pulse can be written as shown in Equation 1:

$$d \quad 4[kdt/Cp]^{1rz} \qquad \text{(Eq. 1)}$$

where

k = heat conductivity of the material being illuminated;
At_a = the pulse-width of the light pulse;
C = the heat capacity of the material;
p^a = density of the material.

It is clear from Equation 1 that the depth of heat penetration can be controlled by the pulse-width of the fight source. Thus, a variation of pulse-width in the range of 10^{-5} sec to 10^{-1} sec will result in a variation in the thermal penetration by a factor of 100.

Accordingly, the flashlarrp 14 provides a pulse width of from 10^{-5} sec to 10^{-1} sec. For treatment of vascular disorders in which coagulation of blood vessels in the skin is the objective the pulse length is chosen to uniformly heat as much of the entire thickness of the vessel as possble to achieve efficient coagulation. Typical blood vessels that need to be treated in the skin have thiGmesses in the range of 0.5mm. Thus, the optimal pulse-width, taking into account the thermal properties of blood, is on the order of 100msec. If shorter pulses are used, heat will still be conducted through the blood to cause coagulation, however, the instantaneous temperature of part of the blood in the vessel and surrounding tissue will be higher than the temperature required for coagulation and may cause unwanted damage.

For treatment of external skin disorders in which evaporation of the skin is the objective, a very short pulse-width is used to provide for very shallow thermal penetration of the skin. For example, at 10^{-5} sec pulse will penetrate (by thermal conductivity) a depth of the order of only 5 microns into the skin. Thus, only a thin layer of skin is heated, and a very high, Instantaneous temperature is obtained so that the external mark on the skin is evaporated.

Figure 3 shows a variable pulse-width pulse forming circuit comprised of a plurality of Individual pulse forming networks (PFN's) that create the variation In pulse-widths of flashlarrp 14. The light pulse full width at half maximum (FWHM) of afiashlamp driven bye single element PFN with capacitance C and inductance L is approximately equal to:

$$At \; .2[LC]^{xa} \qquad \text{(Eq. 2)}$$

Flashlamp 14 may be driven by three different PFN's, as shown in Figure 3. The relay contacts R1', R2' and R3' are used to select among three capacitors C1, C2 and C3 that are charged by the high voltage power supply. Relays R1,

R2 and R3 are used to select the PFN that will be connected to flashlamp 14. The high voltage switches S1, S2 and S3 are used to discharge the energy stored in the capacitor of the PFN into flashlamp 14. In one embodiment Lt, L2 and L3 have values of 100mH, 1mH and 5mH, respectively, and C1, C2 and C3 have values of 100mF 1mF and 10mF, respectively.

In addition to the possibility of firing each PFN separately, which generates the basic variability in pulse-width, additional variation can be achieved by firing PFN's sequentially. ff, for example, two PFN's having pulse-width M1 and M2 are fired, so that the second PFN is tired after the first pulse has decayed to half of its amplitude, then an effective light pulse-width of this operation of the system will be given by the relation: 4t -! Alt +! 412 !.

The charging power supply typically has a voltage range of 500V to 5kU. The relays should therefore be high voltage relays that can Isolate these voltages reliably. The switches S are capable of carrying the current off flashlamp 14 and to isolate the reverse high voltage generated if the PFNs are sequentially fired. Solid-state switches, vacuum switches or gas switches can be used for this purpose.

A simmer power supply (not shown in Figure 3) may be used to keep the flashlamp in a low current conducting mode. Other configurations can be used to achieve pulse-width variation, such as the use of a single PFN and a crowbar switch, or use of a switch with closing and opening capabilities.

Typically, for operation of flashlamp 14 with an electrical pulse-width of 1 to 1 Omsec, a linear electrical energy density input of 100 to 300J/cm can be used. An energy density of 30 to 100J/cm^2 can be achieved on the skin for a typical flashlanp bore diameter of 5mm. The use of a 500 to 650nm bandwidth transmits 20% of the incident energy. Thus. energy densities on the skin of 6 to 20J/em ^{2} are achieved. The incorporation of the fluorescent material will further extend the output radiation in the desired range, enabling the same exposure of the skin with a lower energy input into flashlamp 14.

Pulsed laser skin treatment shows that energy densities in the range of 0.5 to 10J/an^t with pulse-widths in the range of 0.5msec are generally effective for treating vascular related skin disorders. This range of parameters falls in the range of operation of pulsed non-laser type light sources such as the linear flashlamp. A few steps of neutral density glass filters 18 can also be used to control the energy density on the skin.

For external disorders atypical pulse-width of 5 microsecond is used. A 20J/cm electrical energy density input into a 5mm bore flashlamp results in an energy density on the skin of 10J/an^t. Cutting off the hard UV portion of the spectrum results in 90% energy transmission, or skin exposure to an energy density of close to 10 J/an^t. This energy density is high enough to evaporate external marks on the skin.

Device 10 can be provided as two units: a lightweight unit held by a physician using handle 13, with the hand-held unit containing flashlamp 14, filers 18 and iris 20 that together control the spectrum and the size of the exposed area and the detectors that measure the reflectivity and the instantaneous skin temperature. The power supply, the PFN's and the electrical controls are contained in a separate box (not shown) that is connected to the hand-held unit via a flexible cable. This enables ease of operation and easy access to the areas of the skin that need to be treated.

The Invention has thus far been described in conjunction with skin treatment. However, using a flashlamp rather than a laser in invasive treatments provides advantages as well. Procedures such as lithotripsy or removal of blood vessel blockage may be performed with a flashlamp. Such a device may be similar to that shown In Figures 1 and 2, and may use the electronics of Figure 3 to produce the flash. However, to properly couple the light to an optical fiber a number of couplers 40, 80 and 90 are shown in Figures 4 and 8-10, respectively.

Coupler 40 includes an optical source of high Intensity incoherent and isotropic pulsed light such as a linear flash tube 42, a light reflector 44 which delivers the fight energy to an optical filer 46. The latter has a generally conical edge in the embodiment of Figure 4. Optical fiber 46 transfers the light from light collection system 44 to the treatment area. In general, coupler 40 couples pulsed light from a flash tube into an optical fiber and has applications in medical, industrial and domestic areas.

For example, coupler 40 may be used in material processing to rapidly heat or ablate a portion of a material being processed, or to induce a photo-chemical process. Alternatively, coupler 40 may be used in a photography application to provide a flash for picture taking. Using such a coupler would allow the flash bulb to be located inside the camera. with the light transmitted to outside the camera using an optical fiber. As one skilled in the art should recognize coupler 40 allows the use of incoherent light in many applications that coherent or incoherent light has been used In the past

To provide for coupling the light to an optical fiber, flash tube 42 has a toroidal shape, shown in Figures 5 and 6, and is dsposed inside reflector 44. In addition to the toroidal shape other shapes, such as a continuous helix, may be used for flash tube 42. However, a helical tube Is more difficult to manufacture than a toroidal tube. Referring now to Figure 6. flash tube 42 is generally in the shape of a tours, but is not a perfect tours since the electrodes located at the end of the tours have to be connected to the power source. This does not create a significant disturbance in the circular shape of flash tube 42, since the connection to the electrodes can be made quite small.

Reflector 44 collects and concentrates the light, and has a cross-section of substantially an ellipse, in a plane perpendicular to the minor axis of the toroidal flash tube 42. The major axis of this ellipse preferably forms a small angle with the major axis of toroidal lamp 42. The exact value of the angle between the ellipse axis and the main axis of lamp 42 depends on the Numerical Aperture (NA) of the optical fber. The toroidal flash tube is positioned so that its minor

axis!coincides!with!the!focus!off!the!ellipse.!The!other!focus!off!the!ellipse!is!at!the!edge!of!optical!fber!46.!Reflector!44 may!be!machined!from!metal!with!the!inner!surfaces!polished!for!good!reflectivtly.!Aluminum!is!a!very!good!reflector with!high!reflectivity!In!the!visible!and!ultraviolet!wavelengths,!and!it!may!be!used!for!this!purpose.!The!reflector!can!be machined!in!one!piece!and!then!cut!along!a!surface!perpendicular!to!the!main!axis!off!the!device.!This!will!enable!integration!off!the!torddal!flash!tube!into!the!device

As!shown!In!Figure!4,!the!edge!of!optical!fber!46!Is!a!cone!with!a!small!opening!angle,!so!that!the!total!area!of!the fber!exposed!to!the!light!from!the!flash!tube!is!increased.!Referring!now!to!Figure!7!the!geometry!for!coupling!light!into a!conical!tip!is!shown.!It!is!assumed!here!that!the!light!comes!from!a!region!in!space!with!a!refractive!Index!of!n_2 and that!the!conical!section!off!the!fiber!(as!well!as!the!rest!off!the!fber!core)!has!a!refractive!index!of!n_1.

Not!all!the!light!rays!hitting!the!cone!are!trapped!in!it.!For!light!rays!that!propagate!In!a!plane!that!contains!the!major axis!off!the!system,!a!condition!can!be!derived!for!the!angle!of!a!ray!that!will!be!trapped!and!absorbed!in!the!fiber.!This condition!is!shown!in!Equation!3.

$$\sin(\theta_{an}) \le \cos(\theta) \cdot (n_1^2 - n_2^2)^{1/2} \sin(\theta) \qquad \text{(Eq. 13)}$$

Light!will be!trapped in the!conical!portion!of!the!optical!fiber if!the!incidence angle θ!Is larger!than calculated from Equation 3.!Trapping!is!possble!only!if!n_1, n_2.!If!the!medium!outside!of!the!fber!is!air,!n_2-1.!Not!all!of!the!light trapped in!the!conical!section!of!the!fiber!will!also!be trapped in!the!straight!portion!of!the!fiber!if!a!flier!with!a!core!and a!cladding!is!used.!If!a!fiber!with!a!core!and!no!cladding!is!used!(air!cladding),!then!all!the!rays!captured!in!the!conical section!of!the!fiber!will!also!be trapped in!the!straight!section!of!the!fbar.

The!configuration!shown!in!Figure 4 can also!be!used with!a fluid filling!the volume!between the!reflector!and!the optical!fiber.!A very convenient!fluid!for!this purpose may!be!water.!Water!is!also!very effective in cooling the Oashlamp if high!repetition!rate!pulses!are!used. The presence of!a!fluid!reduces!the!losses!that!are associated with glass!to!air transitions,!such!as!the!transition!between!the!flashlamp!envelope!material!and!air.!If!a!fluid!is!used!in!the!reflector!volume,!then!its!refractive!index!can!be!chosen!such!that!all!the!rays trapped In!the!conical!section!are!also!trapped!in!the fiber,!even!if!core/cladding!fibers!are!used.

Mother!way!of!configuring!the!fber!in!the!reflector!is!by!using!a!fiber!with!a!flat edge. This configuration is!shown In!figure!8!and!has trapping!efficiency!very close!to!the!trapping!efficiency!of!the!conical edge. Many!other!shapes!of the!fiber!edge,!such!as!spherical!shapes,!can!also!be!used.!The!configuration!of!the!fiber!edge!also!has!an!effect!on the!distrbution!of!the!light!on!the!exit!side!of!the!fiber!and!it!can!be!chosen!in!accordance!with!the!specific!application of!the!device.

The!device!may!be!used with a variety of!optical!fibers.!Single,!or!a!small!number!of!millimeter!or!sub-millimeter diameter!fbers,!will!typically!be!used!in!invasive!medical!applications.!In!other!applications,!particularly!in!industrial!and domestic!applications,!it!may!be!preferable!to!use!a!fiber!having!a!larger!diameter,!or!a!larger!bundle!of!fibers,!or!a!light guide.

According!to!one!embodiment!flexible!or!rigid!light!guides!are!used!to!couple!the!light!to!the!treatment!area.!Flexible light!guides!made!from!a!bundle!of!quartz!or!other!glass!fibers that!are fused together!by!heat!at!the!edge of the bundles. The!bundles!may!be!circular, rectangular, or!any!other!useful!shape.!Rigid!light guides may!be made from!quartz, acrylic,!glass,!or!other!materials!having!a!high degree of transparency. The!material!is generally!highly!polished on!all sides.

A!typical!cross!section!of!a!circular!light!guide!useful!for!therapeutic!treatment!Is!one!mm!to!ten!mm!in!diameter. Alternatively,!a!rectangular!light!guide!maybe!used!having!typical!dimensions!of!3!mm!by!10!mm!to!30!mm!by!100!mm. In!either!case!the!length!may!be!20!to!300!mmm,!or!as!needed!for!the!specific!application.

According!to!another!alternative!embodiment!a!rectangular!light!guide!is!used!to!more!efficiently!couple!the!light. The!rectangular!light!guide!is!chosen!to!have!a!shape!that!matches!a!rectangular!linear!flashlamp!and!to!match!the shape!of!the!vessel!being!treated.

The!light!guides!described!above!may!be!used!in!another!alternative!embodiment!to!control!the!spectrum!of!light delivered!to!the!treatment!area.!Spectral!control!can!be!achieved!by!making!the!light!guide!from!a!material!that!had!an absorbing!dye!dissolved!therein.!Thus,!light!transmitted!by!the!light!guide!will!have!a!spectrum!in!as!determined!by!the absorbing!dye. Alternatively, a flat,!discrete!filter!may!be!added to one!end!(preferably!the!input end) of the light!guide. Both!of!these!filters!are absorbing filters.!The!inventors!have!found!that absorbing filters produced!by Schott,!having Model!Nos.!00515,!OG550,!OG570,!and!00590!have!suitable!characteristics.

Additionally,!interference!filters!or!reflective!coatings!on!the!light!guide!may!be!used!by!applying!a!proper!optical coating!to!the!light!guide.!Again,!a!single!discrete!interference!filter!could!also!be!used.!Additionally,!combinations!of the!various!filters!described!herein,!or!other!filters,!may!be!used.!The!use!off!the!filters!described!here!may!render!the use!off!the filters described!earlier with reference to!Figure!1!redundant.

An alternative!embodiment entails!the!use!of application specific!light!guides.!In!this!way!the spectra of!light!for!various!treatments!can!be easily!controlled. According!to!this alternative each!type!of!treatment!will!be performed with!a specific!light!guide.

The optical properties of the tight guide will be chosen to optimize the particular treatment. The wavelengths below are particularly useful for the respective treatments:

arteries less than 0.1 mm in diameter - 520 - 650nm
veins less than 0.1 mm In diameter - 520 - 700nm
- vessels between 0.1 and 1.0 mm in diameter - 550-1000nm

larger vessels - 600 - 1000nm

In each case if the skin is darker (higher pigmentation) longer wavelengths on the lower cut-off portion of the spectrum should be used.

Multiple spectra maybe used for optimal penetration. This maybe accomplished by illuminating with a few pulses, each having a different spectrum. For example, the first pulse can have a spectrum that is highly absorbed in blood. This pulse will coagulate the blood, thereby changing the optical properties of the blood, making it more absorbing in another wavelength range (preferably longer). A second pulse will be more efficiently absorbed since the blood absorbs energy off a greater wavelength range. This principle may be used with lasers or other light sources as well.

In addition to the features of the light guides discussed above, a light guide is used, in one alternative embodiment, to control the angular distribution of the light rays impinging on the skin. Light that Impinges on the skin at large angles (relative to the perpendicular) will not penetrate very deeply into the tissue. Conversely, light that impinges perpendicularly to the skin will have a deeper penetration. Thus, it is desirable to provide a distribution of light *rays* that has a relatively wide angular divergence when the treatment requires shallow penetration. Alternatively, a narrow divergence is preferable for treatment requiring deep penetration is desired. Some treatment might require both shallow and deep penetration.

Figure 15 shows a light guide 115 having an exit beam with a greater angular divergence than that of the entrance beam. As shown In Figure 15, a beam 116 enters light guide 115 at a small angle, relative to the axis of fight guide 115. When beam 501 exits light guide 115. the angle, relative to the axis, is much greater. The tapered shape of light guide 115 enhances this divergence.

Figure 16 shows a straight light guide 118 that maintains the angular distrbution of the rays of light that enter into it. A beam 119 is shown entering and exiting light guide 118 with the same angle, relative to the axis of coupler 601. Alternate use of both light guides 115 and 118 can achieve the narrow and deep penetration discussed above. Alternatively, the user can select the type of coupler according to the depth of penetration needed for the treatment being performed.

Figures 9 and 10 show a coupler 90 for coupling a linear flash tube 92 through a linear to circular fiber transfer unit 94 to a fiber bundle 96. A reflector 98 has an elliptical cross-section, shown in Figure 10, in a plane parallel to the axis of linear flash tube 92 in this embodiment Tube 92 is located on one focus of the ellipse while the linear side of linear to circular bundle converter 94 is located at the other focus of the ellipse. This configuration is relatively simple to manufacture and commercially available linear to circular converters such as 25-0044 available from General Fiber Optics may be used. This configuration is particularly useful for larger exposure areas of the finer, or for flash illumination purposes.

The energy and power densities that can be achieved by this invention are high enough to get the desired effects in surface treatment or medical applications. For the embodiment shown in Figure 4 the total energy and power densities can be estimated as follows. For a typical toroidal lamp with a 4mm bore diameter and a major diameter of 3.3cm an electrical linear energy density input of 10J/cm into the lamp can be used with a 5p.sec pulse width. The light output off the lamp will be 5 to 6J/cm for optimal electrical operating conditions. For the reflector shown in Figure 4, 50 % of the light generated in the lamp will reach the lower focus. Thus, a total energy flux on the focus of 25 to 30J may be obtained. For embodiments shown in Figure 4 or Figure 8 the total cross-section area of reflector at the focal plane has a cross-section of 0.8cm^2. Energy densities on the order of 30 to 40J/cm^2 at the entrance to the fiber should be attained with this cross-section. This corresponds to power densities of 5 to 10MW/cm^2, which are the typical power densities used in medical or material processing applications.

For longer pulses, higher linear electrical energy densities into the lamp can be used. For a 1 msec pulse to the flash tube a linear electrical energy density of 100J/cm can be used. The corresponding energy density at the focal area would be up to 300J/cm^2. Such energy densities are very effective in industrial cleaning and processing applications as well as in medcal applications.

Alternative embodiments for coupling the optical fiber to an extended light source such as a linear flashlamp are shown in Figures 11 and 12. In the embodiment of Figure 11 an optical User 101 is wound around a lamp 102 and a lamp envelope 103. Some of the light that is produced by the light source is coupled into the fiber. If the light rays are propagating in the direction that is trapped by the fiber then this light will propagate in the fber and it can be used at a fiber output 104. One limitation of this configuration is the fact that most of the light emitted by lamp 103 travels in a direction perpendicular to the surface of lamp 103 and cannot be trapped in fiber 101.

The embodiment shown in Figure 12 overcomes this problem. A doped optical fber 1051s wound around lamp 102 and envelope 103, rather than an undoped User such as fiber 101 of Figure 11. The dopant is a fluorescent material which is excited by the radiation emanating from lamp 102 and radiates light inside the fiber. This light is radiated Omni-

directionally and the part of it that is within the critical angle of fber 105 is trapped and propagates through the fber and can be used at fber output 104. The angle of light that is trapped in the fber is the critical angle of the material from which the optical fiber or optical wave guide is made. For a fber (or optical wave guide) in air this angle is given by sin a. Un.

Typically for glass or other transparent materials n . 1.5 and a . 41.8°. This corresponds to a trapping efficiency of more than 10% of the light emitted by fluorescence inside the fber. If we assume a 50% efficiency of the fluorescence process we find out that more than 5% of the light produced by the lamp is trapped and propagated down the fber. For example, a 4" lamp with a linear electrical energy input of 300J/Inch and 50% electrical to light conversion efficiency would couple 2.5% of its electrical energy into the fber. This corresponds, for the 4' lamp case to a total light energy of 30J of light. This embodiment has the additional advantage of transferring the wavelength emitted by the lamp to a wavelength that may be more useful in some of the therapeutic or processing applications mentioned before. Thus, fluorescent material doped in the fiber can be chosen in accordance with an emission wavelength determined by the specific application of the device.

One alternative embodiment includes the use of a gel to couple the light to the skin. This alternative reduces heating of the outer layer of the skin (the epidermis and upper layers of the dermis). The gel is preferably a high viscosity water based gel and is applied to the skin before treatment, although other gels that are not necessarily water based may be used. A gel having a relatively high heat capacity and thermal conductivity, such as a water based gel, is preferable to enable cooling of the outer skin (the epidermis in particular). Transparency is also desirable because during treatment light passes through the transparent gel and reaches the skin.

Referring now to Figure 13, a gel 110 is applied to the skin 21 prior to the treatment A flat layer of gel on top of the skin is used since irregularities in the upper layer of the gel through which the light passes may cause scattering of the light and reduce its penetration into the skin. In order to achieve this flatness a solid, transparent, flat piece 111 maybe applied on top of the skin. The configuration is shown schematically in Figure 13. The transparent plate can be made out of glass or other transparent materials. Either the flashlamp housing or the light guides discussed above may be placed in direct contact with the transparent plate.

The configuration of Figure 13 has the advantage of reducing the scattering of light (represented by arrows 113) that enters into the skin due to Irregularities in the surface of the skin. The skin has an Index of refraction that is larger than that of the air. As a result, any photon that impinges on the air skin interface is deflected if it does not hit the skin at an incidence angle of M. Since the surface of the skin is Irregular the angular distribution of the skdn increases. This is shown schematically in Figure 14.

The use of gel addresses this problem since the gel can fill irregular voids that are created by the skin structure. The transparent plate that covers the gel and the gel itself will preferably have an index of refraction that is close to that of the skin. This is relatively easy since the index of refraction of the skin is of the order of 1.4 in the visble and the near infrared. Most glasses and transparent plastics have indices of refraction that are of the order of 1.5 which Is close enough. The index of refraction of water is of the order of 1.34 in this range. Water based gels will have similar Indices of refraction. The index can be increased by proper additives. The plate and gel thus act as a flat surface for the light to impinge upon. Because the gel and plate have an Index of refraction close to that of the skin there is very little scattering at the gel plate and gel-skin interfaces.

The use of a gel has been experimentally successful in the treatment of leg veins and other benign vascular lesions of the skin. The treatments were caned out with the flashlamp described above. However, in alternative embodiments a different incoherent source, or a coherent source, maybe used.

During operation light is typically applied to the skin in a sequence of three pulses with short delays between the pulses. This mode of operation is used in order to take advantage of the faster cooling of the superficial, thin (less than 0.1mm thick) epidermis compared to the larger and deeper vessels typical of leg veins. The gel in contact with the skin cools the epidermis during the waiting period between the pulses. This cooling reduces significantly the damage to the epidermis.

In accordance with the invention, light is applied to the treated area in either a long pulse or in a sequence of pulses separated by a delay. The delay and/or pulse length is preferably controlled by the operator to provide enough heat to accomplish the desired treatment but not enough heat to damage the skin.

This concept was tested with large and deep vessels (of the order of 2mm in diameter and 2mm deep). A thin layer of commercial water based ultrasound gel (1 to 2mm thick, 'Aqua dear' gel made by Parker USA) was applied on the skin. A 1 mm thin glass window was used to generate a flat layer of the gel. The light from the device passed through the thin glass and the gel and into the skin. Care was taken to assure than no air bubbles exist in the gel. This configuration was tested with photon fluences of 30 to 50J/cm^2. Coagulation and clearance of the vessels was obtained without causing damage to the skin. This Is contrary to simllar trials in which gel was not used and in which fluences of 20J/cm^2 with the same pulse structure caused burns of the skin.

The epidermis has a thickness of approximately 0.1 mm and a cooling ti me of about 5 msec. Thus, to avoid burning delays greater than 5 msec are used.

In another!alternative embodiment!the!spectrum!of!the!light!used!for!treatment!is controlled!by!controlling the!voltage!and/or current applied!to the flashlamp. As!is!well!known!in!the!art,!the!spectrum!of!light produced!by!a!flashlamp Is dependent!on!the!voltage!and current provided!to the flashlamp. According to this embodiment the!input voltage!and current!is!selected!to!provide!a!desired!treatment!spectrum.!The!appropriate!voltage!and!currents!may!be!determined experimentally!for!each!flashlamp!used.!For!example,!a!flashlamp!current!of!200!a Pps!produced!the!spectra!shown!in Figure!17.!Similarly, the!spectra of Figure 18!was produced using a!tlashlamp current of!380 amps.!The spectra!of Figure!17!shows!a!significant enhancement In!the wavelength!range of 800-1000nm. Such!a spectra is particularly useful for!treatment!of!large!vessels.

The!different!currents and!voltages!used!to control!the!output spectra!may!be!obtained using!a group!or!bank!of capacitors!that!are!capable!of!being!connected!in!either!series!or!parallel!as!part!of!the!power!source!for!the!flashlamp. A!series connection will provide a relatively!high!voltage!and!high current thereby!producing a spectra having energy in!a!shorter wavelength, such as!500-650 nm. Such!a series connection will be!more!appropriate!for!generating shorter pulses!(1 to!10 msec.!e.g.)!useful!for treatment!of smaller!vessels.

A parallel connection!provides!a lower current and!voltage,!and thus produces!an output spectra!of a longer wavelength,!such as!700-1000 nm.!Such a!spectra is more!appropriate for treatment!of larger vessels!end is!suitable!for!producing longer pulses!(in!the!range!of 10-50 msec,!e.g.).!The selection!of series or!parallel!connections!may!be!done using!a relay!or sets!of relays.

In one!alternative!embodiment the!pulse!forming!network!of!Figure!3!Is replaced!by!a GTO driver circuit!121,!such as!that!shown!in!Figure!19.!The!driver!circuit!of Figure 19!uses!a!switch capable!of!being turned both!on!and off to control!the application of power to!the!flashlamp.!While!this alternative!embodiment will be!described with respect!to!a GTO being!used!as the!switch,!other!switches capable!of!being turned both!on!and off,!such as IGBTs, amy!also!be used.

Referring!now!to!Figure 19,!driver!circuit!121!includes!a!high voltage source!122, a!capacitor!bank!C5,!an inductor L5. a!diode!D5, a!switch!GT01,!a diode D6,!a diode D7,!a!resistor R5,!a!capacitor!C6, a!GTO!trigger generator TR1,!a resistor M. a capacitor C7 and!a flashtube trigger!generator TR2.!These components are connected!to!flashlamp!14 and!serve!to!provide the power pulses to!flashlamp 14. The!duration and!timing of the!pulses are!provided In accordance with!the description herein.!Driver!121 operates in!the!manner described below.

High!voltage source 122 Is connected across capacitor!bank C5,!and!charges capacitor!bank!C5!to!a!voltage suitable!for!application!to!flashlamp!14.!Capacitor!bank!C5!may!be!a!comprised!of!one!or!more!capacitors,!and!may!be configured in!the!manner described!above.

Prior to illumination of!flashlamp!14!flashtube trigger generator!TR2!breaks down flashlamp!14!and!creates a!relatively!low impedance channel!therein.!After!the flashlanp!breaks down, capacitor C7!dumps!current!into!flashlamp!14, further!creating!a!low impedance channel!in!flashlamp!14.!In!this!manner!a predischarge is provided!that!prepares 1lashlamp!14!for!the power pulse. Capacitor C7 provides!a small!amount!of!current!relative!to capacitor!bank CS.!Alternatively,!driver!circuit!121 may!operate in!a!simmer!mode,!wherein!the predischarge is!not!necessary.

Thereafter, switch!GTO1!is!turned!on via!a pulse!from!GTO!trigger generator TR1, completing!the circuit between tlashlamp!14 and!capadtor!bank C5.!Thus, capacitor!bank C5!discharges!through!flashlamp!14.!An!inductor!L5 may!be provided!to!control!the!rise!time!of!the!current!through!flashlamp!14.!Inductor!L5!may!include!an!inherent!resistive!component,!not!shown.

After!a length of!time!determined!by!the!desired!pulse!width!has passed, G1O!trigger generator TR1 provides a pulse!to!switch!GT01,!turning!it *off*. A!control!circuit!determines!the!timing!of!the!trigger!pulses!and provides them!in accordance!with!the!desired!pulse!widths!and!delays.

A!snubber!circuit comprised!of diode D6, resistor R5, and!a!capacitor C6 is!provided!for!switch!GTO1.!Also, diodes D5!and!D7!are!provided!to!protect!switch!GT01!from!reverse!voltages.!Resistor!R7!is!provided!in!parallel!with!flashlamp *14* to!measure!the!leakage!current!of!switch!GT01,!which!can!in!turn be *used* to!make!sure!that!switch!GT01!is!operating!properly.

A!possible!addition!to driver circuit!121!is!to provide an!SCR!or!other!switch!in!parallel!with capacitor!bank C5.!This allows!the!discharge!or!resetting!of!capacitor!bank!C5!without!turning!on!switch!GT01.!Other!modifications!may!be made,!such!as!providing!the!circuit!with!a!serial!trigger,!rather!than!the!parallel!trigger!shown.!Another!modification!is to!use!the!driver!circuit!with!a!laser!rather!than!flashlamp!14.

Proper!use!of!pulse!widths!and!delays!can!aid!in!avoiding!burning!the!epidermis.!The!epidermis!has!a!cooling!time of about 5 msec,!while large!vessels!have a longer!cooling time (a 1 mm!vessel!has!a!cooling!time of!about!300 msec). Thus,!during a pulse of!duration!longer!than!5 msec the!epidermis can!cool down but the vessel!will!not. For!example, for treatment!of a large vessel!(such as!one!having!a!diameter!of!about 1mm)!a!pulse of!100 cosec!will!allow!the skin!to cool,!but!the!vessel!will!not!cool.

The same effect may!be!achieved using!trains of pulses.!This!is!useful!when!it!is!not!practical!to provide!a single long!pulse!to!the!flashlamp.!The!delays between pulses!are!selected!to!allow!the!skin!to!cool,!but!to!be!too!short!for!the vessel to cool.!Thus,!larger vessels can be!treated with longer!delays!because!they!have!greater!cooling times. Small vessels!cool quickly and long delays are!not effective.!However,!they!also!need less energy!and can be!treated effectively!in!a!single!pulse.

Typical delay times are in the range of 20 msec to 500 msec. More specifically, delays of between 100-500 msec are effective for vessels larger than 1 mm in diameter. Delays of between 20-100 msec are effective for vessels between 0.5 and 1 mm in diameter. Delays of between 10-50 msec are effective for vessels between 0.1 and 0.5 mm in diameter. A single pulse having a width in the range of 1 meek to 20 msec is effective for vessels less than 0.1 mm diameter.

Additionally, delays should be selected according to skin pigmentation. Darker skin absorbs more energy and needs more time to cool: thus longer delays are needed. Lighter skin absorbs less energy and can accommodate shorter delays.

It has been found that multiple pulses avoids 'purpora' or the explosion of smell vessels In or dose to the skin. The use of pulses to avoid burning and provide cooling will be effective for light provided by lasers or other sources as well.

Another alternative embodiment includes the use of a microprocessor or personal computer to control the flashlamp. The microprocessor can be used to provide the timing functions and prompt the trigger signals descrbed above. Additionally, In one embodiment the microprocessor Includes a user interface, such as a screen and keyboard, buttons. mouse, or other Input device. The microprocessors have information stored therein that aids in the selection of treatment parameters.

For example, if the condition being treated is a port wine stains skin type III, the physician inputs that condition into the microprocessor. The microprocessor responds with suggested treatment parameters, such as using a 570nm cut-off fitter, a double pulse with a delay of 50 msec and a fluence of 55 J/cm^2. The physician can alter these suggested parameters, but need not refer back to operating guidelines for suggested parameters.

The microprocessor or personal computer can also be used to create and store patient information in a database. Thus, past treatment information such as condition being treated, treatment parameters, number of treatments, etc. is stored and may be recalled when the patient is again treated. This aids In providing the proper treatment to the patient. Additionally, the database may include photographs of the patient's condition before and after each treatment. Again. this aids in record keeping and determining what treatments are most successful for given conditions.

In addition to the treatments descrbed above the devices and methods described herein maybe used to treat other conditions. For example, psoriasis and warts have been successfully treated. Similarly, skin rejuvenation (treating wrinkles) should be effective. The inventor further contemplates using this invention to treat hemorrhoids. throat lesions. and gynecological problems associated with vascular malformations.

Thus, it should be apparent that there has been provided in accordance with the present Invention a flashlanp and coupler that fully satisfy the objectives and advantages set forth above. Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

Claims

1. A therapeutic treatment device for treating a treatment region comprising an incoherent, pulsed, light source operable to provide a light output for treatment, a power supply connected to the light source, a housing Including a reflector and having an opening, wherein the light source Is disposed within the housing and the reflector reflects light from the light source to the opening, and a flexible light guide is disposed between the opening and the treatment region, wherein the light guide receives the incoherent light from the light source and transmits the light to the treatment region and the light source, reflector and light guide cooperate to provide between 6 and 100 J/cmz to the skin, characterized in that

   the light guide transmits light having a predetermined angular divergence, wherein the divergence is selected in response to a desired treatment depth.

2. The treatment device of claim 1 further characterized in that:

   a first interference fitter Is disposed between the light source and the light guide; and

   a second absorbing fitter is disposed between the first fitter and the treatment region.

3. The treatment device of claim 3 further characterized in that

   the light guide is made from a material including an absorbing dye and is the second absorbing filter.

4. The treatment device of claim 1 further characterized in that the reflector includes a reflecting portion that is a portion of a circle.

5. The treatment device of claim 4 further characterized in that the reflecting portion is relatively close to the light source.

6. The treatment device of claim 5 further characterized in that a cooling gel is disposed over the treatment area.

7. A!method!for!therapeutically!treating!a!treatment!region!comprising!the!steps!of!producing!incoherent,!pulsed,!light in!a!housing,!reflecting!the!light!to!an!opening!in!the!housing,!transmitting!the!light!from!the!opening!to!the!treatment area!through!a!light!guide!to!provide!between!6!and!100!J/crn$_2$ to!the!skin,!characterized!in!that:
the!light!guide!transmits!light!such!that!the!light!has!a!predetermined!angular!divergence!and!the!divergence is!selected!in!response!to!a!desired!treatment!depth.

8.!The!treatment!method!of!claim!7!further!characterized!in!that:
the!light!is!filtered!by!a!first!interference!filter,!between!the!light!source!and!the!light!guide:!and
the!light!is!filtered!by!a!second!absorbing!filter!between!the!first!filter!and!the!treatment!region.

9. The!treatment!method!of!claim!8!further!characterized!in!that
the!light!is!filtered!by!the!second!absorbing!filter!as!the!light!passes!through!the!light!guide.

10. The!method!device!of!claim!7!further!characterized!in!that!the!step!of!reflecting!includes!the!step!of!reflecting!the light!by!a!reflector!that!a!portion!of!a!reflecting!surface!is!a!portion!of!a!circle.

11. The!treatment!method!of!claim!10!further!characterized!in!that!the!reflecting!portion!is!relatively!close!to!the!light source.

12.!The!treatment!method!of!claim!7!further!including!the!step!of!applying!a!cooling!gel!to!the!treatment!area.

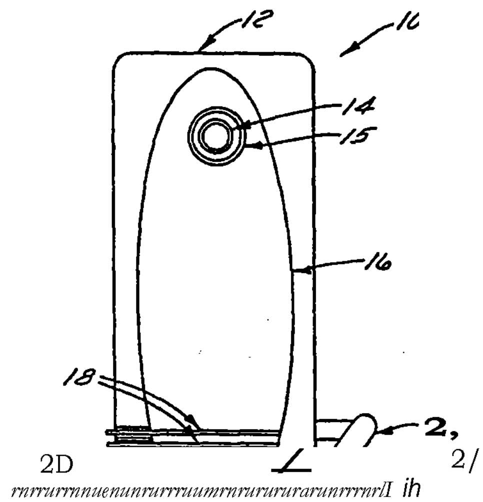


FIG. 9

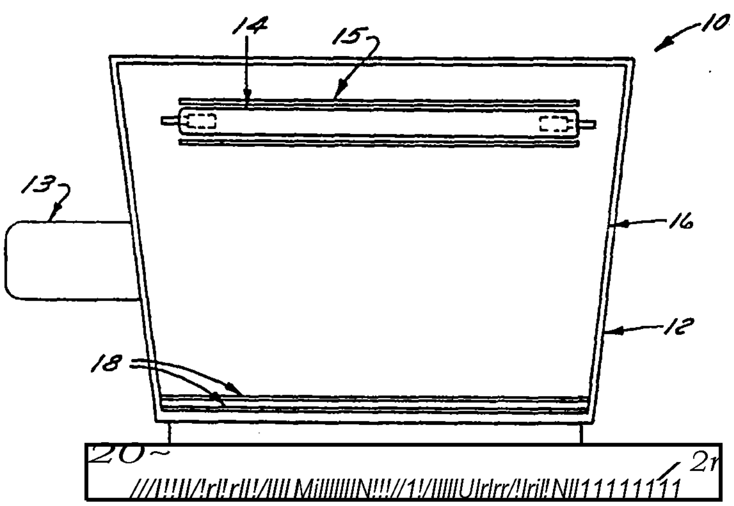
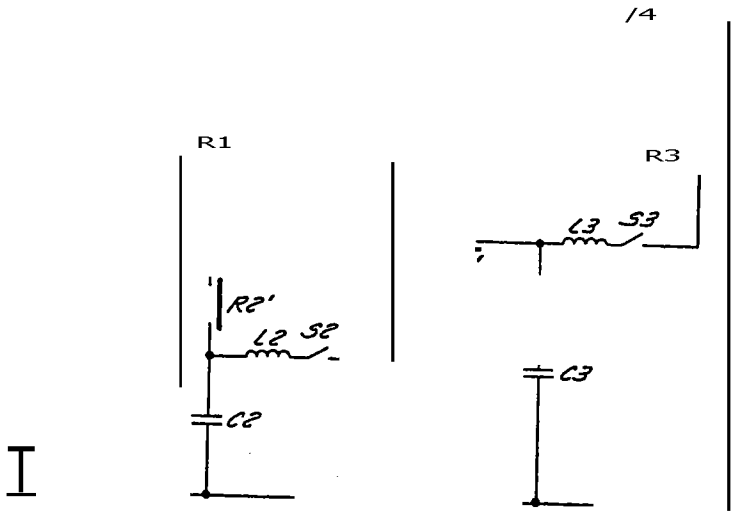


FIG. 2



Ni„

F/G. 3

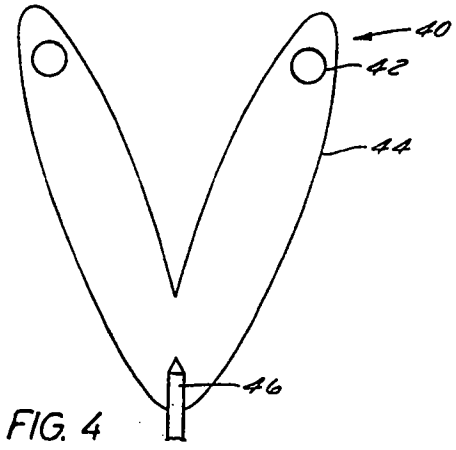
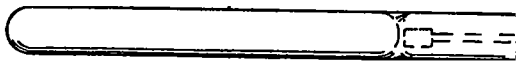
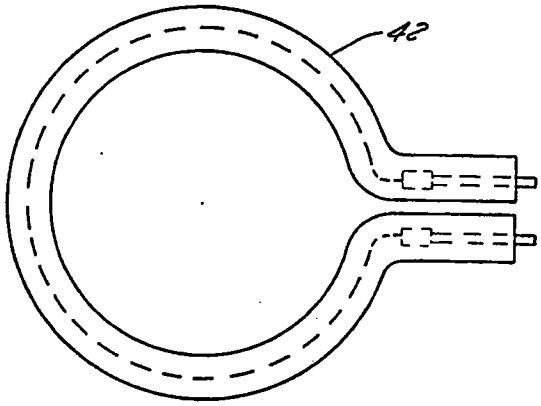


FIG. 4



F/G. 5



F/G. 6

12

FIG 11

/24

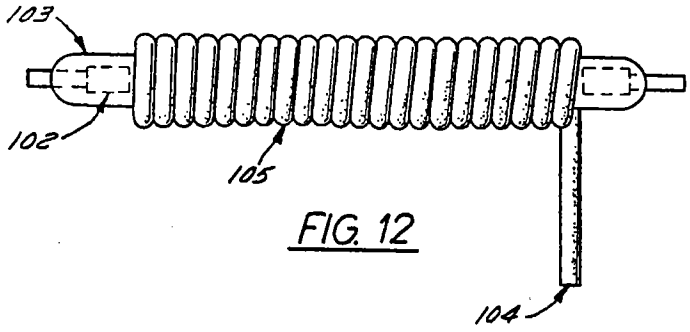


FIG. 12

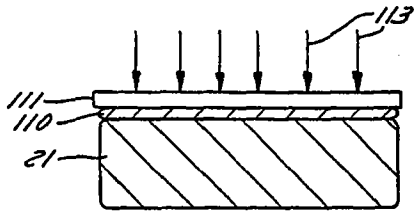


FIG. 13

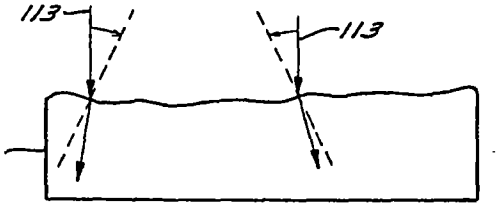


FIG. 14

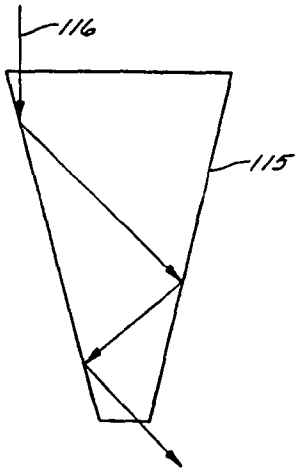
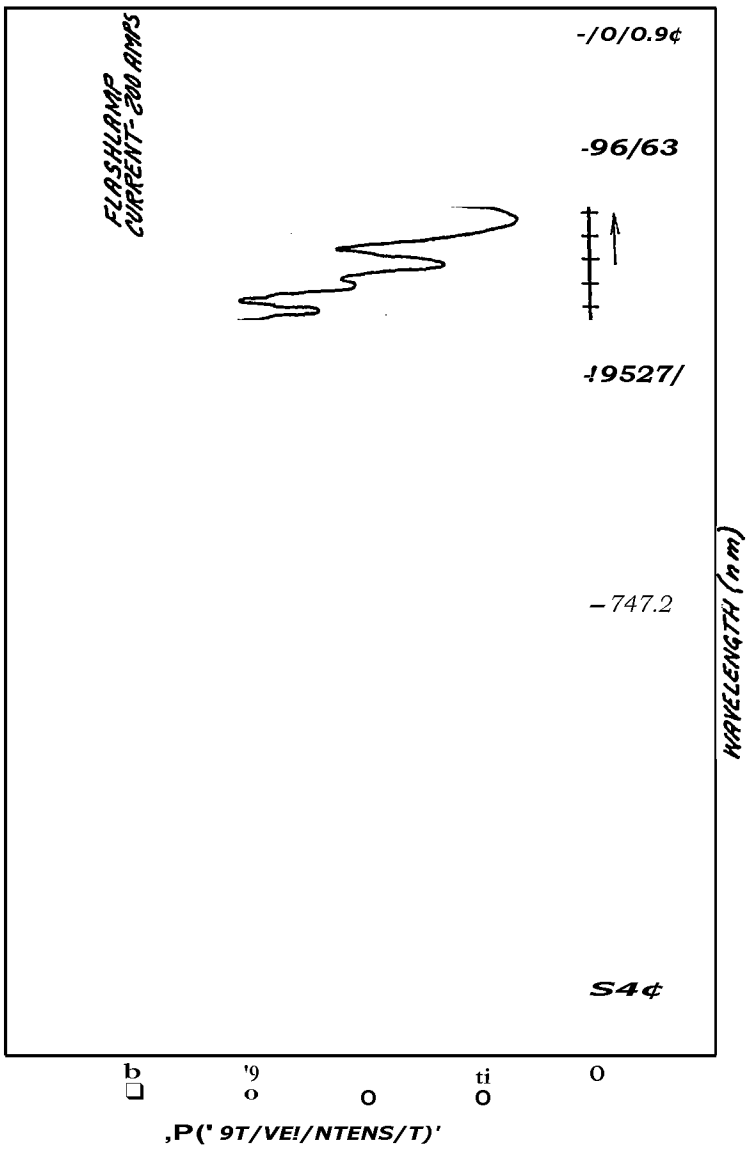


FIG. 15

FIG. 16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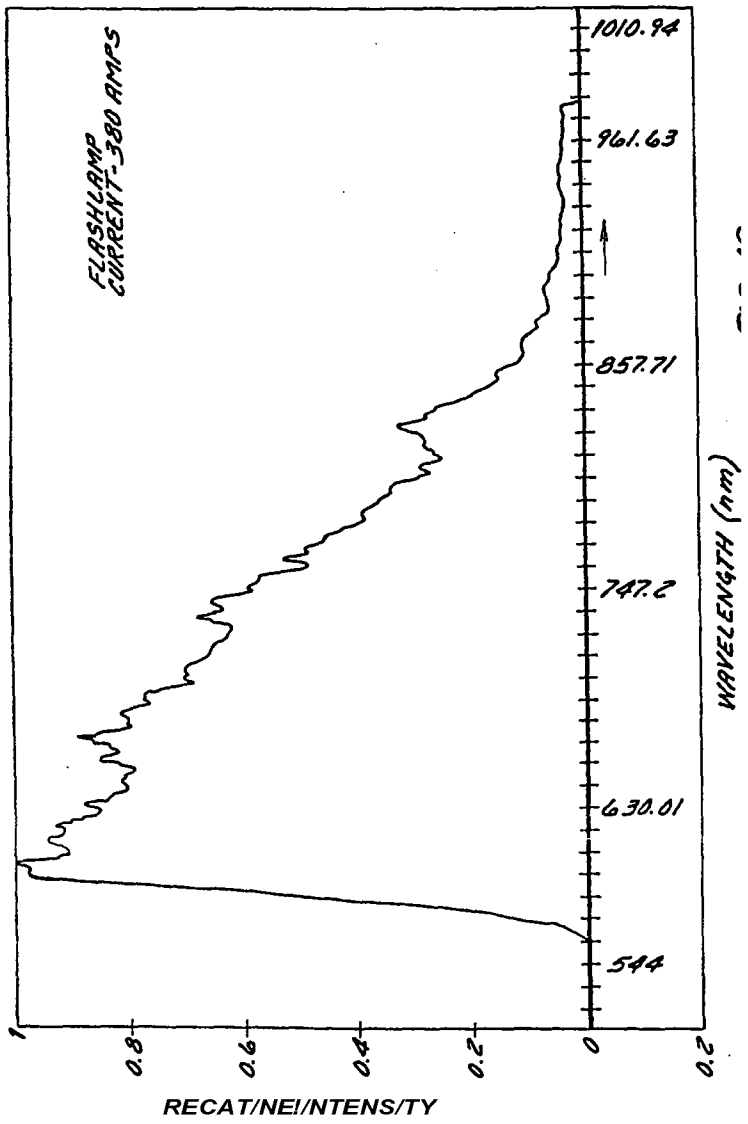
-96/63
-!9527/
-747.2
S4¢
WAVELENGTH (nm)
,P(' 9T/VE!/NTENS/T)'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0.4
0.2
0
0.2
RECAT/NEI/NTENS/TY

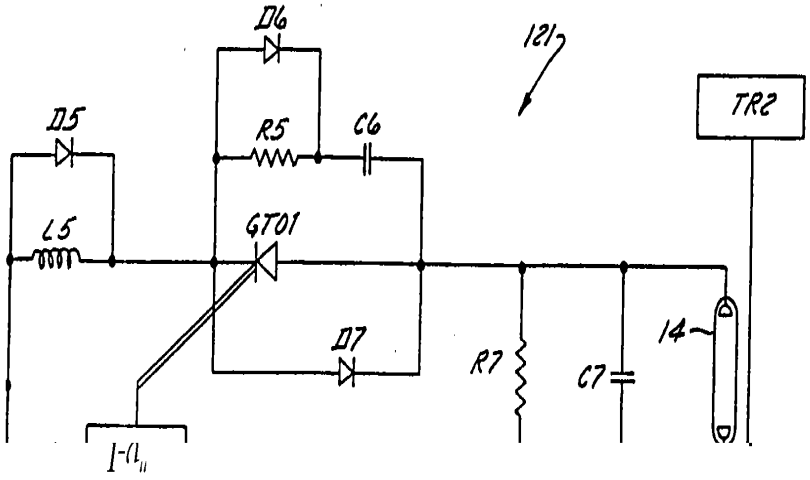

FIG 19